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(54) **SYSTEM AND METHOD FOR OPTIMALLY FORMING GRATINGS OF DIFFRACTED OPTICAL ELEMENTS**

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G02B 27/42 (2006.01)
G02B 27/01 (2006.01)

(52) **U.S. Cl.**

CPC ***G02B 27/4205*** (2013.01); ***G02B 5/1857*** (2013.01); ***G02B 27/0103*** (2013.01)

(58) **Field of Classification Search**

CPC G02B 1/00; G02B 5/18; G02B 2005/1804; G02B 5/1847; G02B 5/1852;

(Continued)

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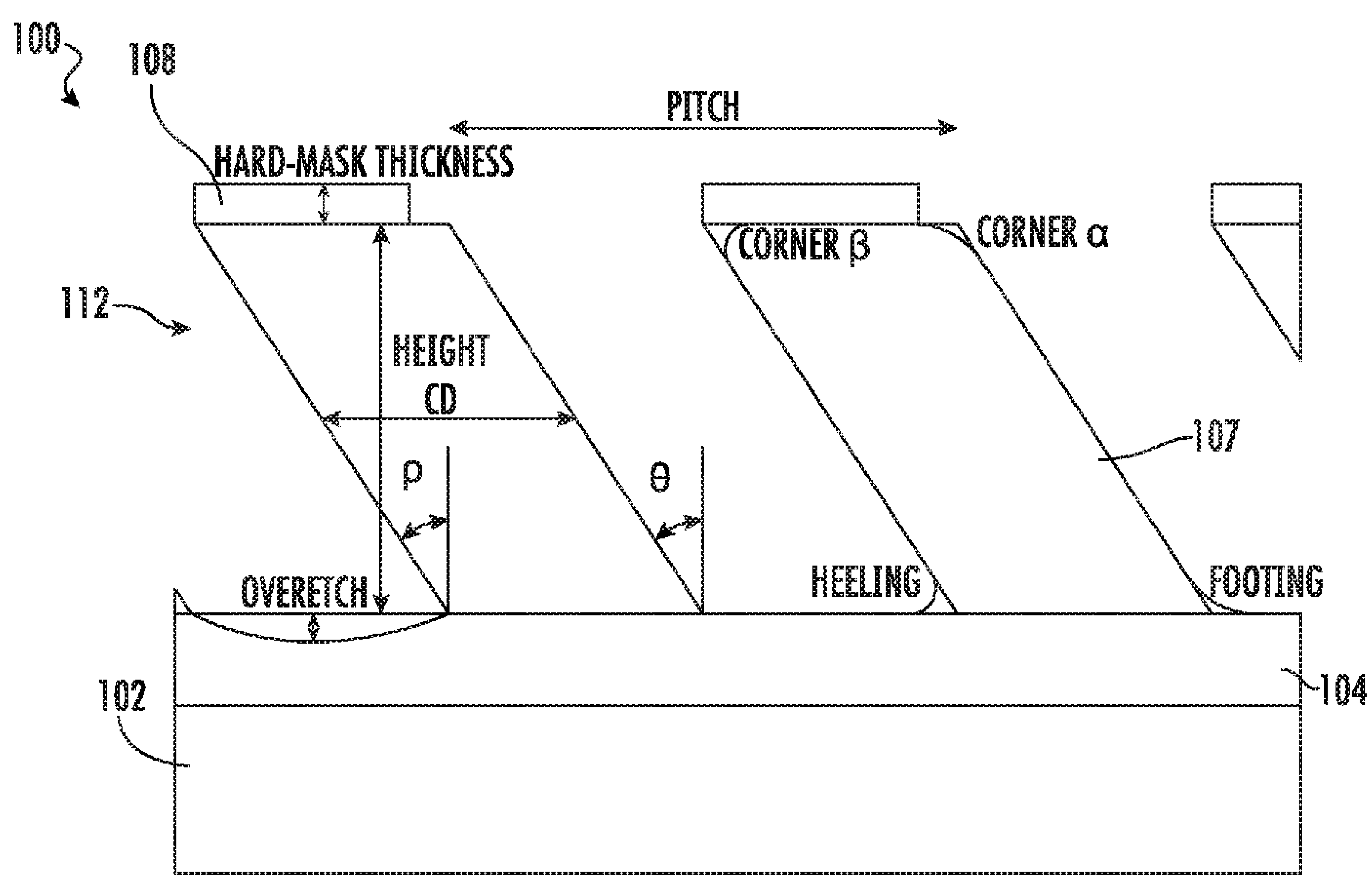
(57) **ABSTRACT**

Optical grating components and methods of forming are provided. In some embodiments, a method includes providing an optically transparent substrate, and forming an optical grating layer on the substrate. The method includes forming an optical grating in the optical grating layer, wherein the optical grating comprises a plurality of angled components, disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate. A first sidewall of the optical grating may have a first angle, and a second sidewall of the grating has a second angle different than the first angle. Modifying process parameters, including selectivity and beam angle spread, has an effect of changing a shape or dimension of the plurality of angled components.

16 Claims, 8 Drawing Sheets



(58) **Field of Classification Search**

CPC G02B 5/1857; G02B 5/1866; G02B 27/42; G02B 27/4205; G02B 27/01; G02B 27/0101; G02B 27/0103; G02B 27/0109; G02B 27/017; G02B 27/0172; G02B 2027/0174; G02B 2027/0178

USPC 359/13, 558, 566, 569, 570, 571, 574, 359/575, 576, 630; 216/24, 65, 66, 67, 216/69, 70

See application file for complete search history.

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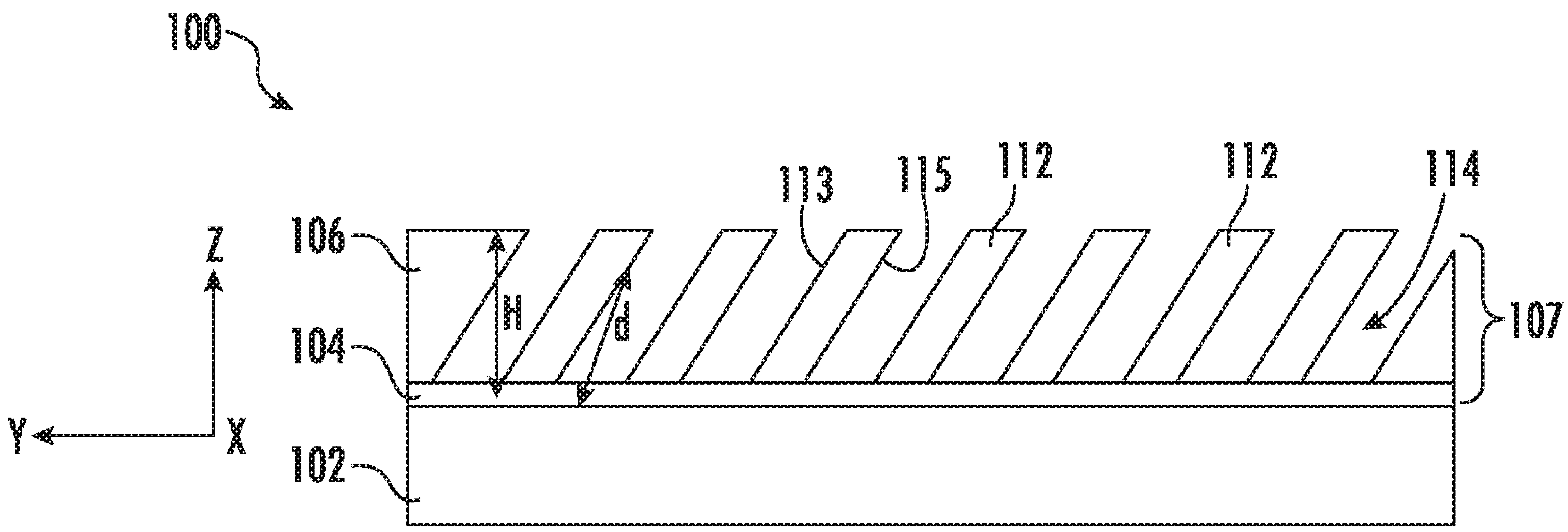

100
106
104
102
113
115
112
112
114
107
H
d
Z
Y
X

FIG. 1A

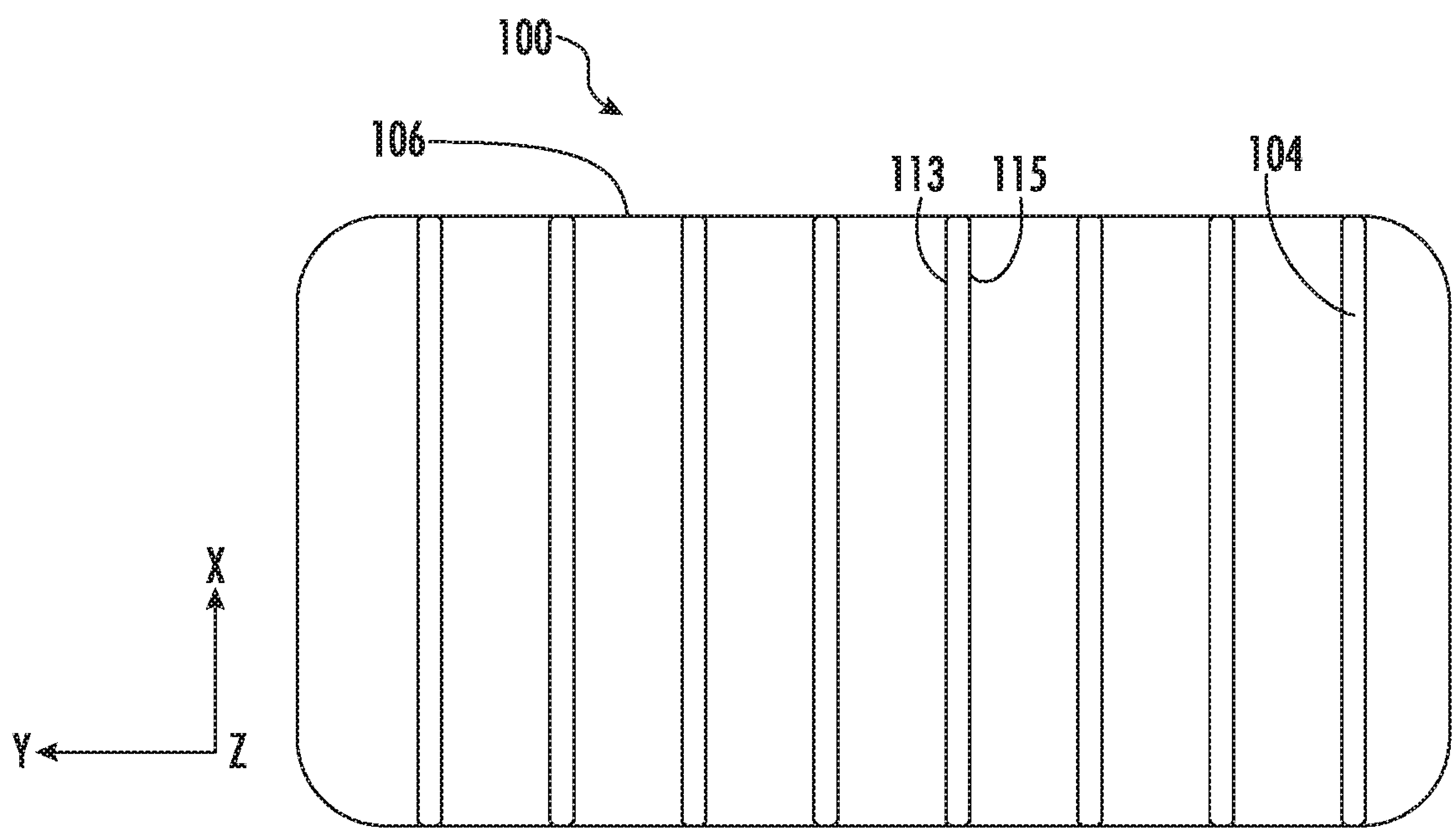

100
106
113
115
104
X
Y
Z

FIG. 1B

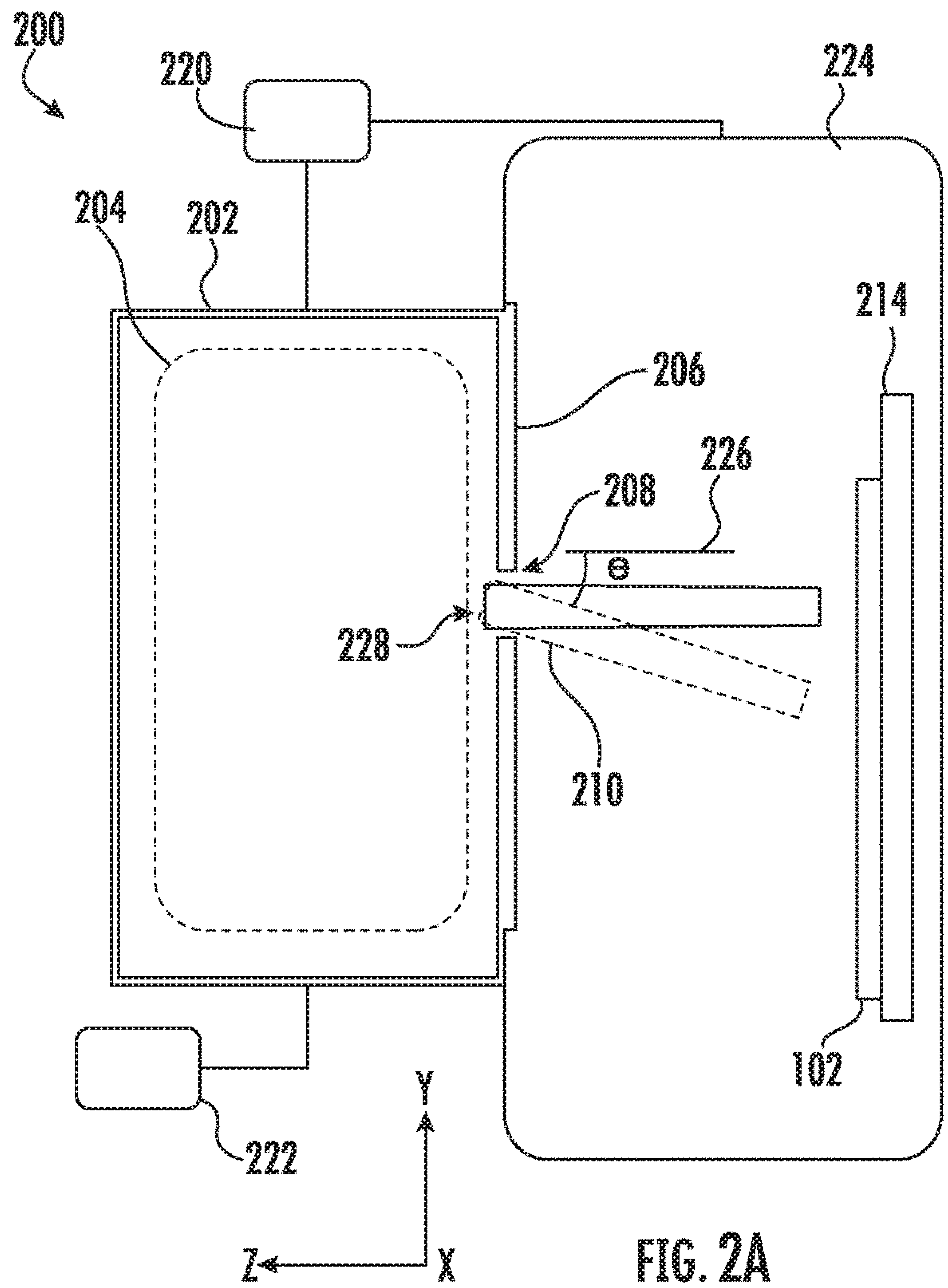

200
220
224
204
202
214
206
226
208
Θ
228
210
102
222
Y
Z
X

FIG. 2A

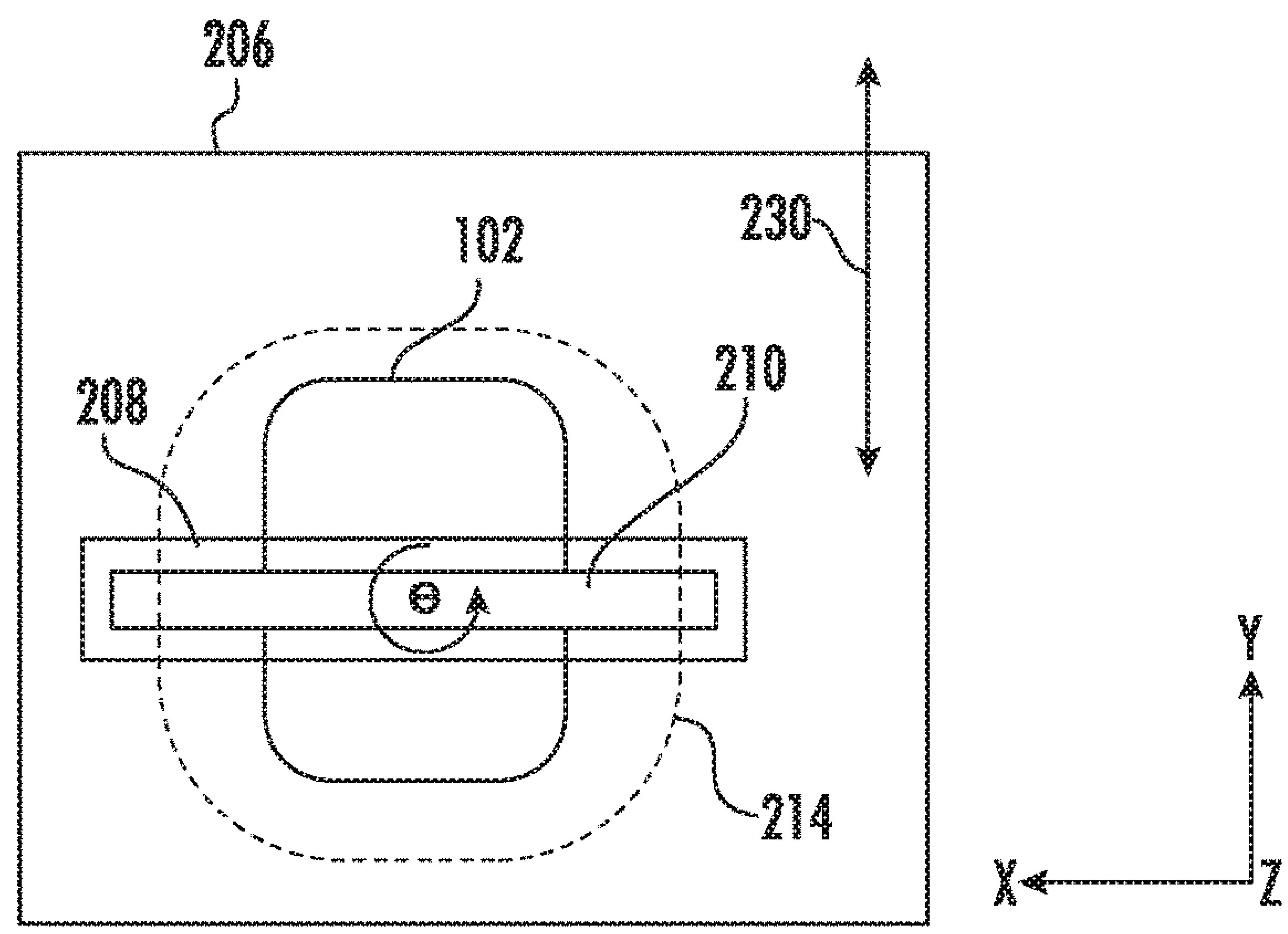

206
230
102
210
208
Θ
214
Y
X
Z

FIG. 2B

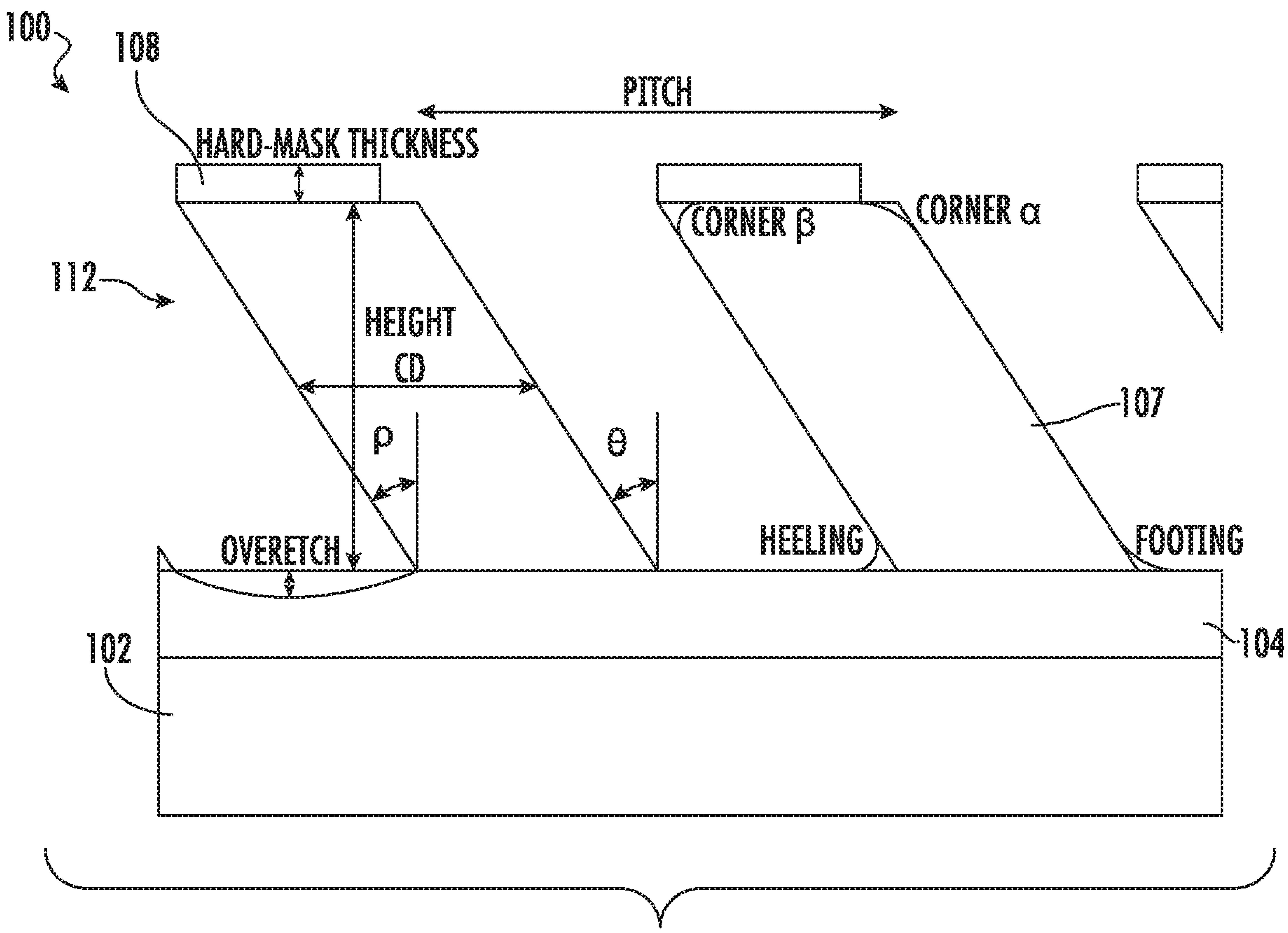

100
108
HARD-MASK THICKNESS
PITCH
CORNER β
CORNER α
112
HEIGHT
CD
107
ρ
θ
OVERETCH
HEELING
FOOTING
102
104

FIG. 3

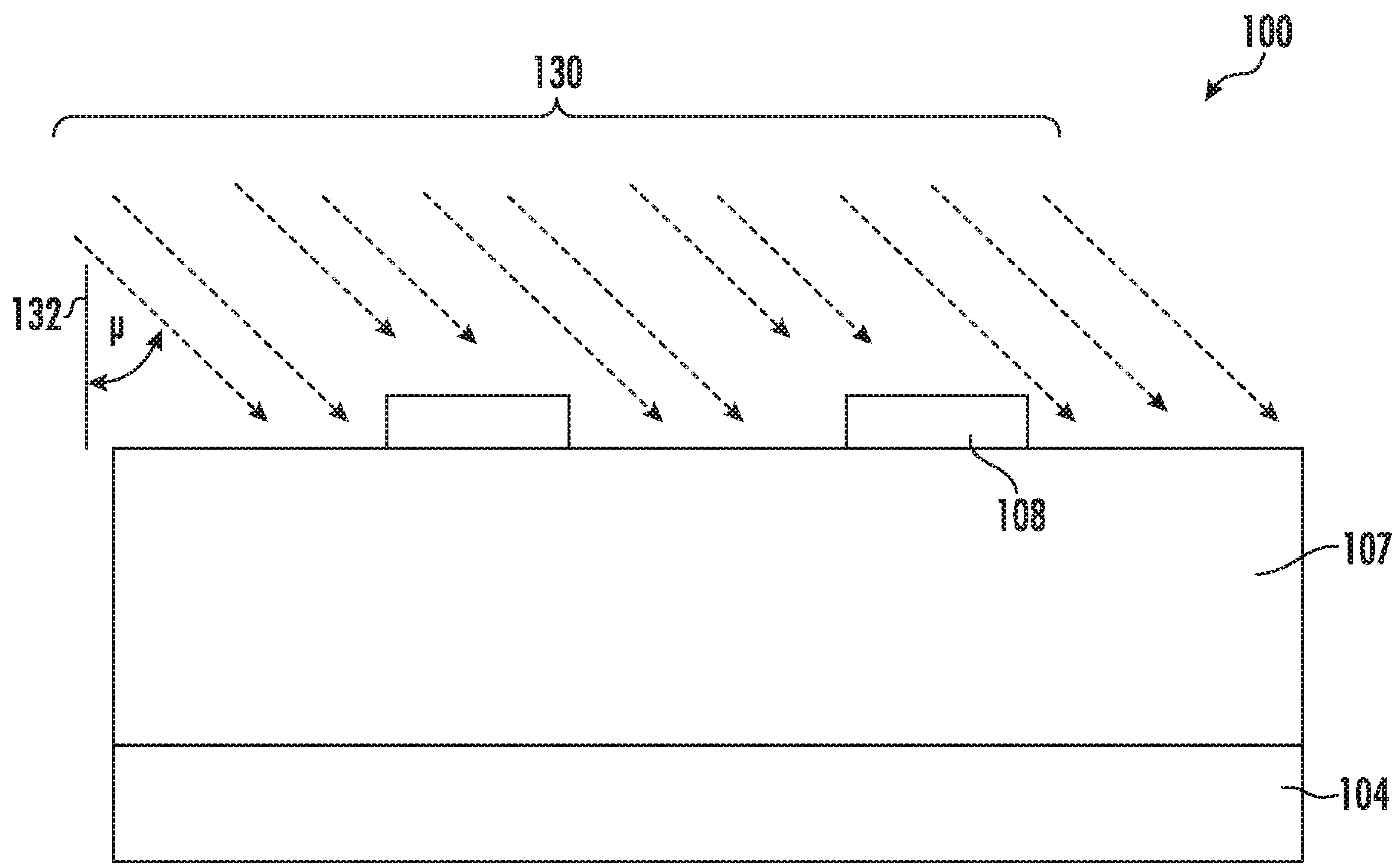

100
130
132
μ
108
107
104

FIG. 4A

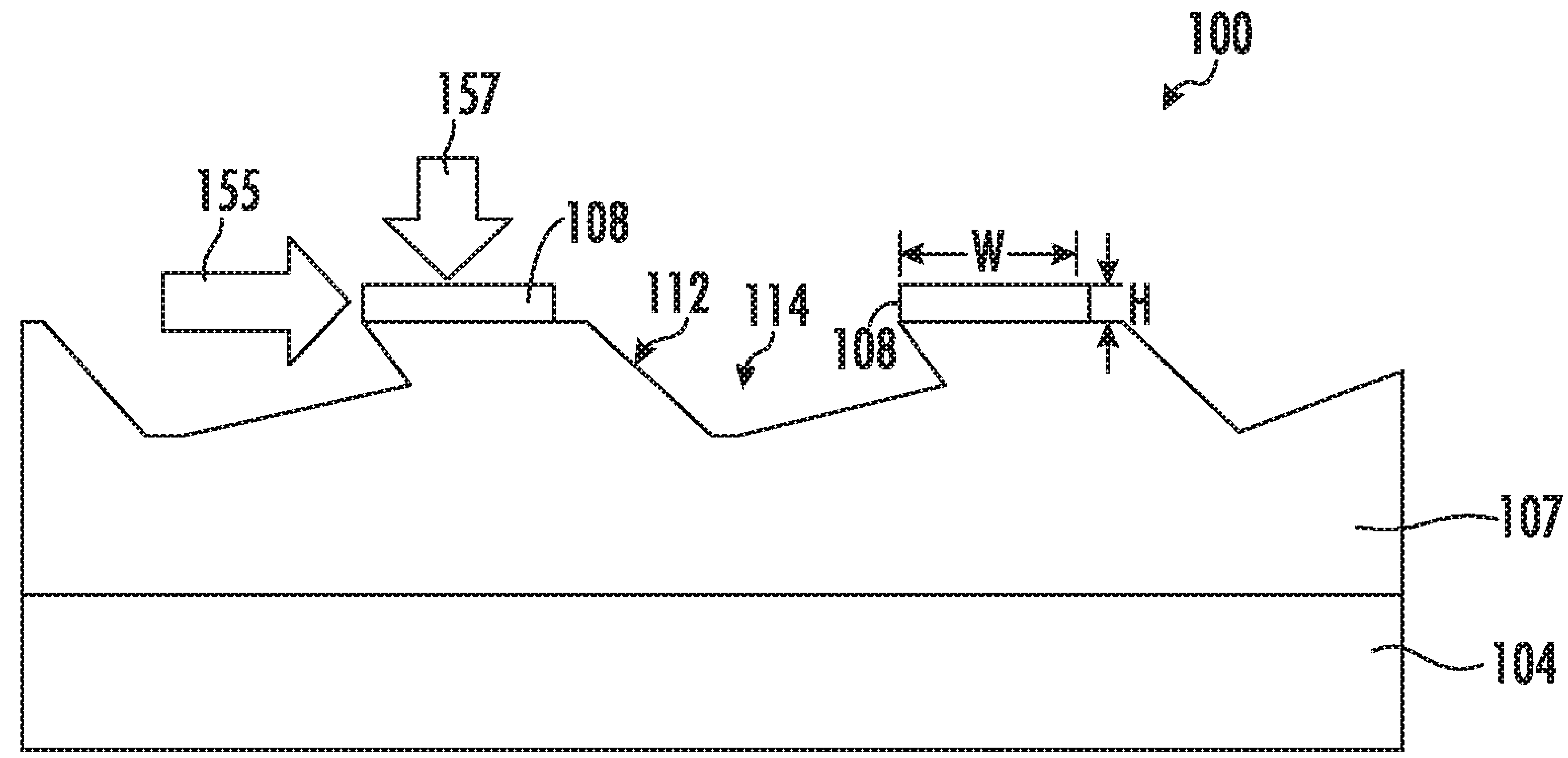


FIG. 4B

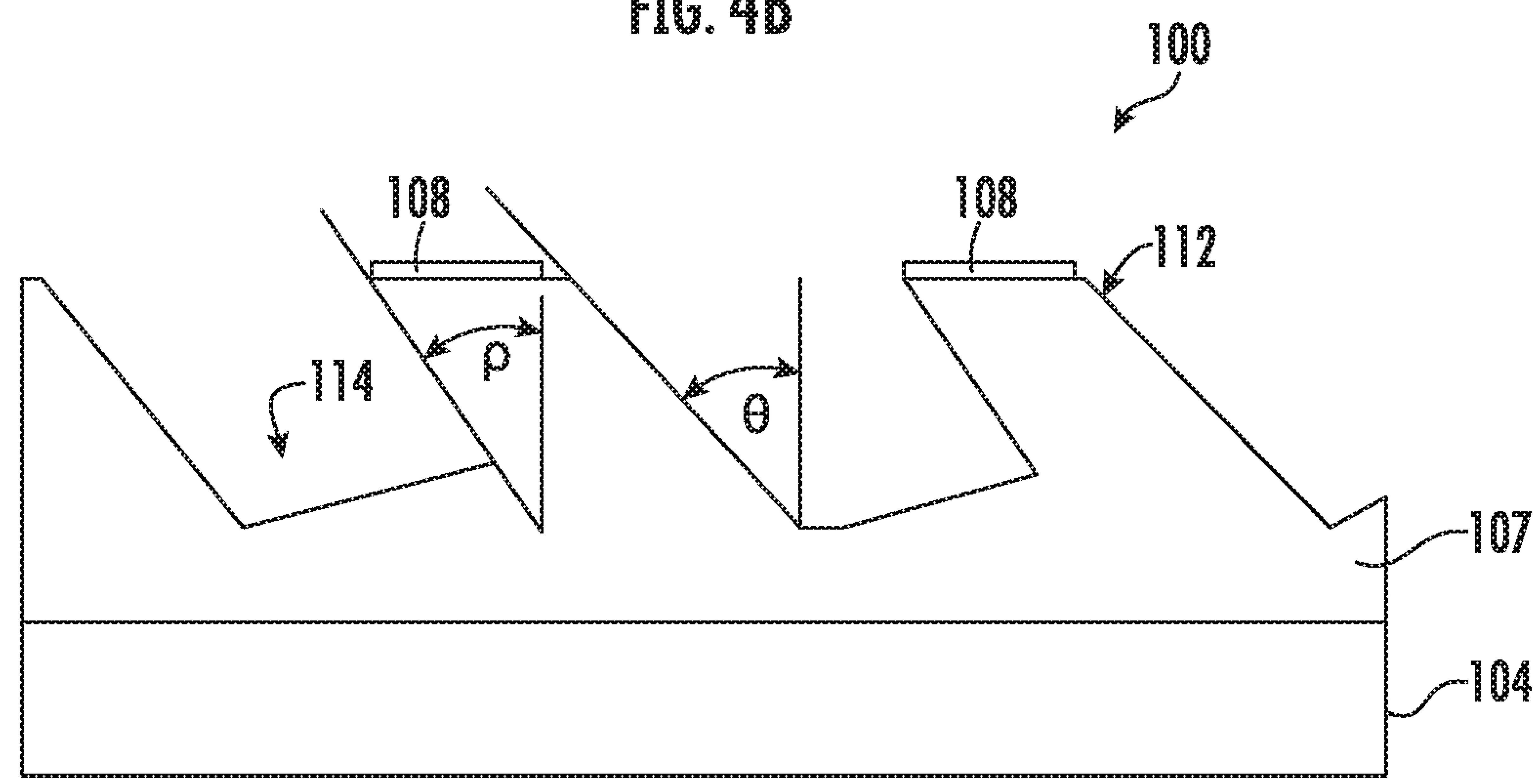


FIG. 4C

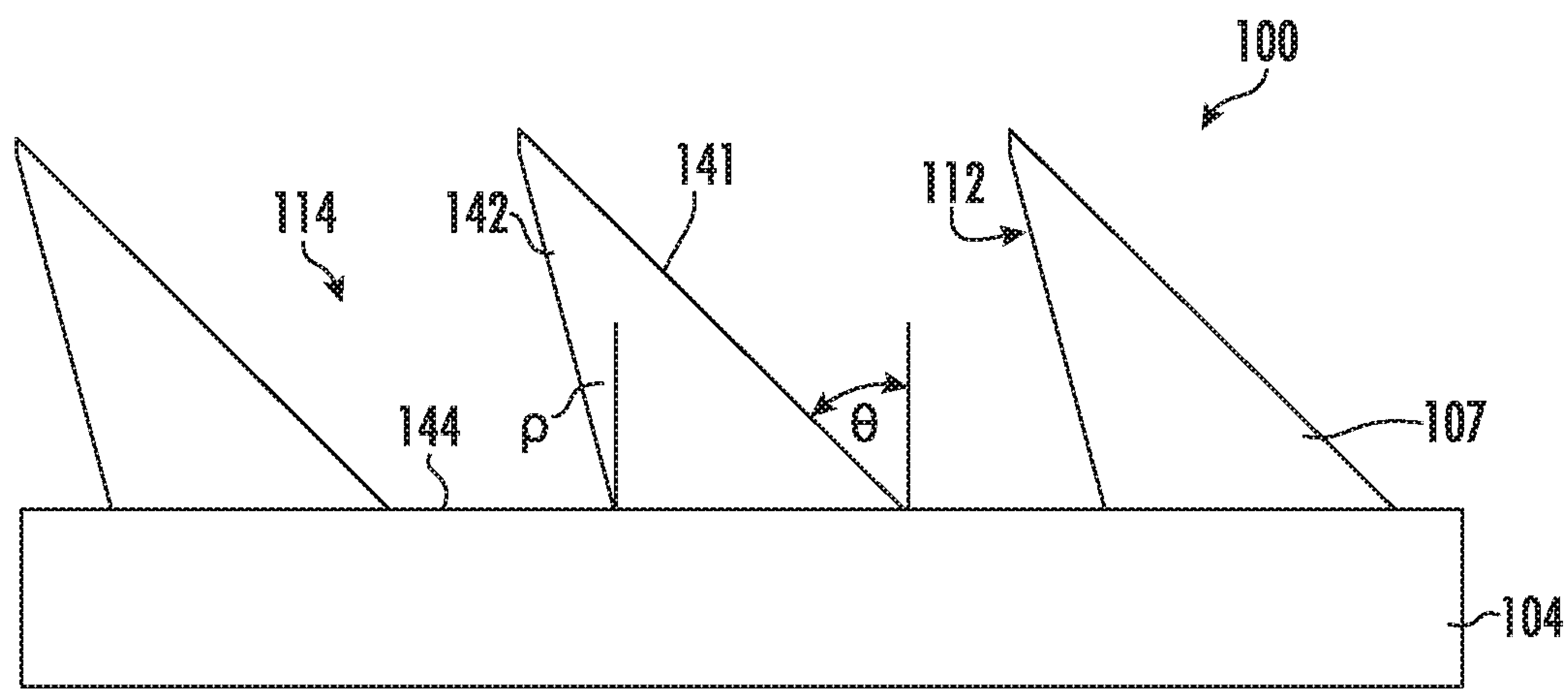
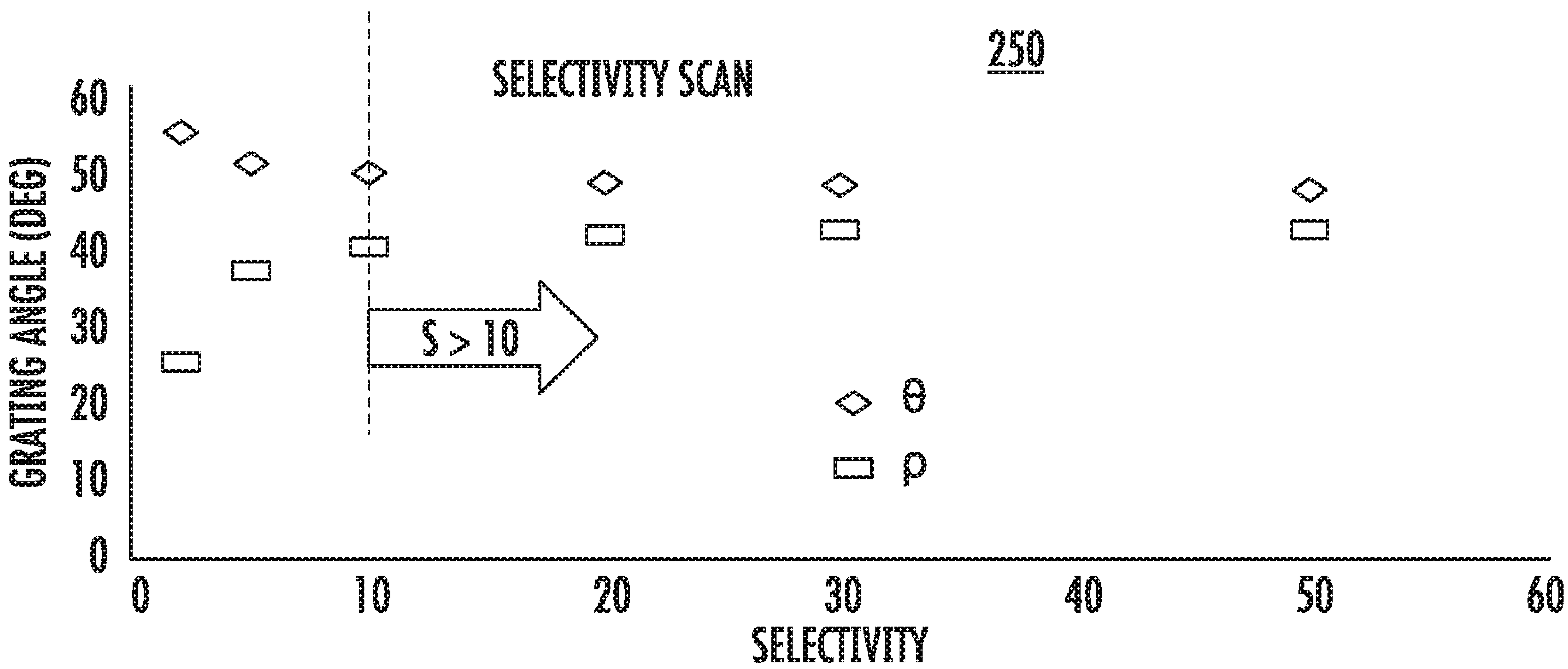


FIG. 4D



SELECTIVITY SCAN
250
GRATING ANGLE (DEG)
60
50
40
30
20
10
0
S > 10
θ
ρ
0
10
20
30
40
50
60
SELECTIVITY

FIG. 5

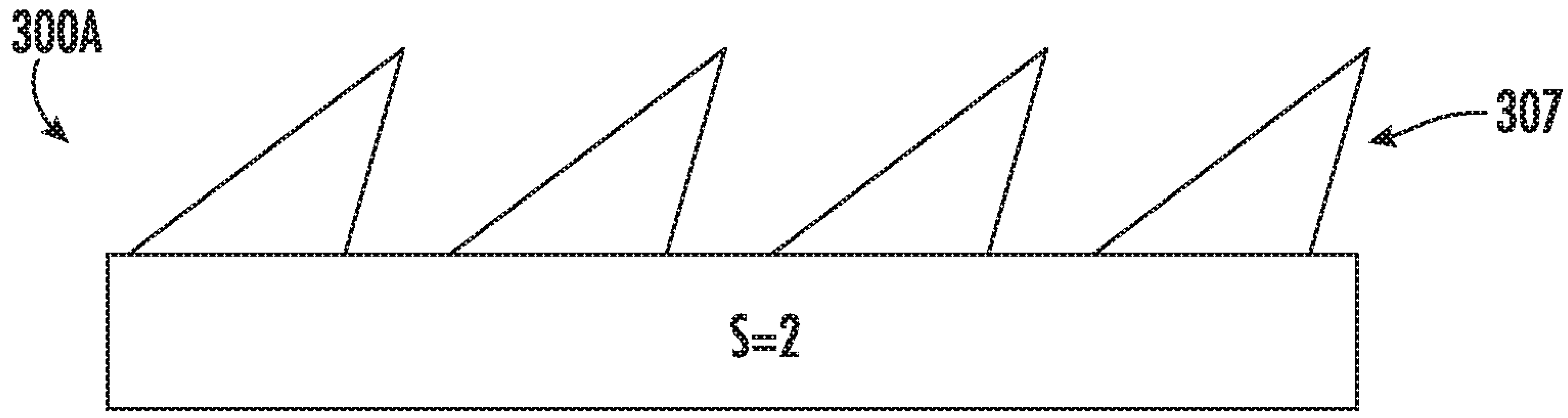


FIG. 6A

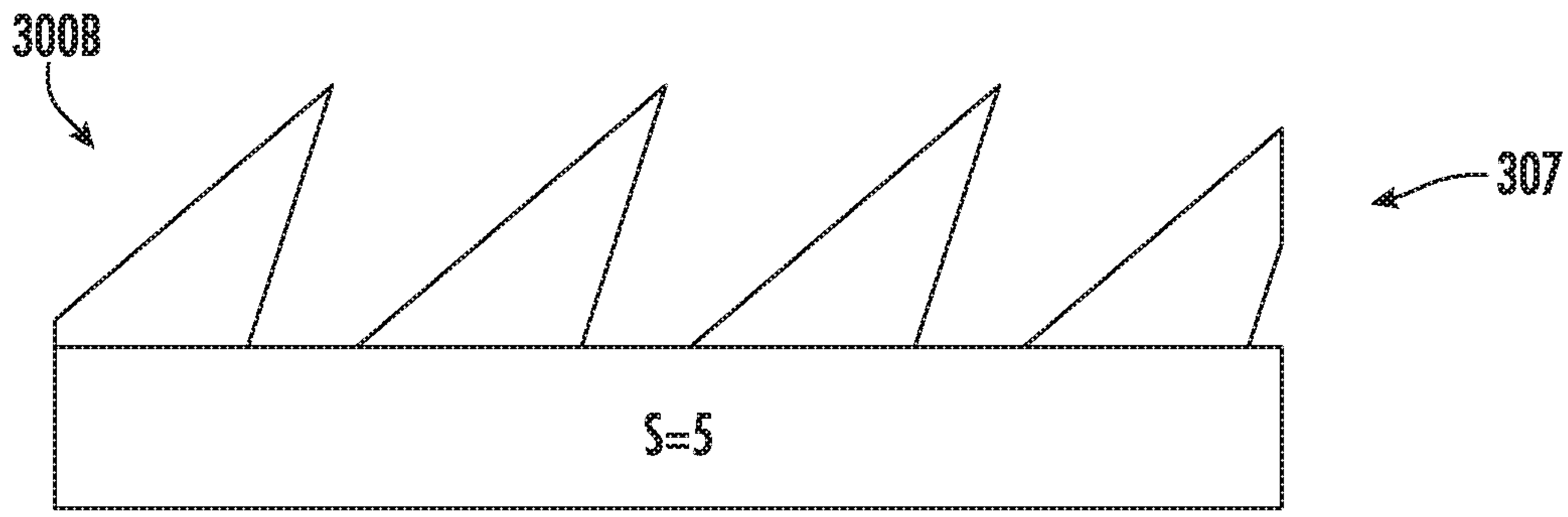


FIG. 6B

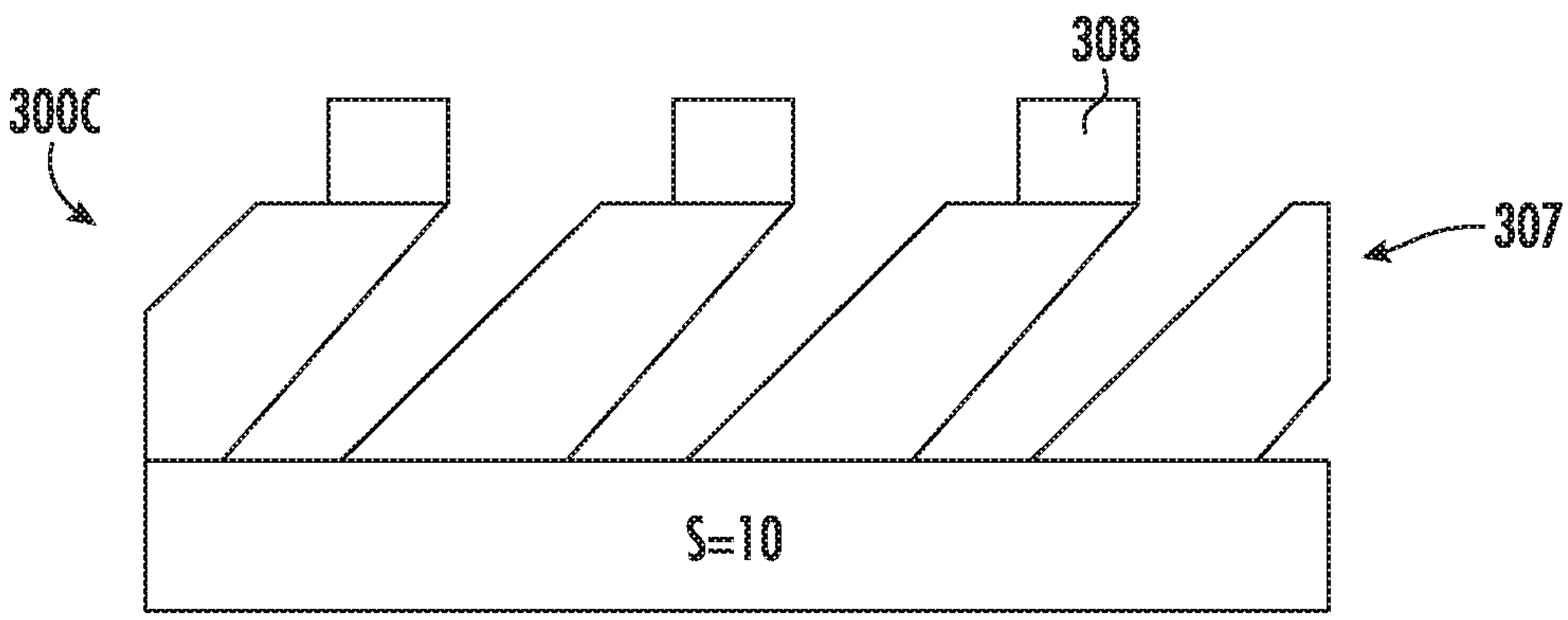


FIG. 6C

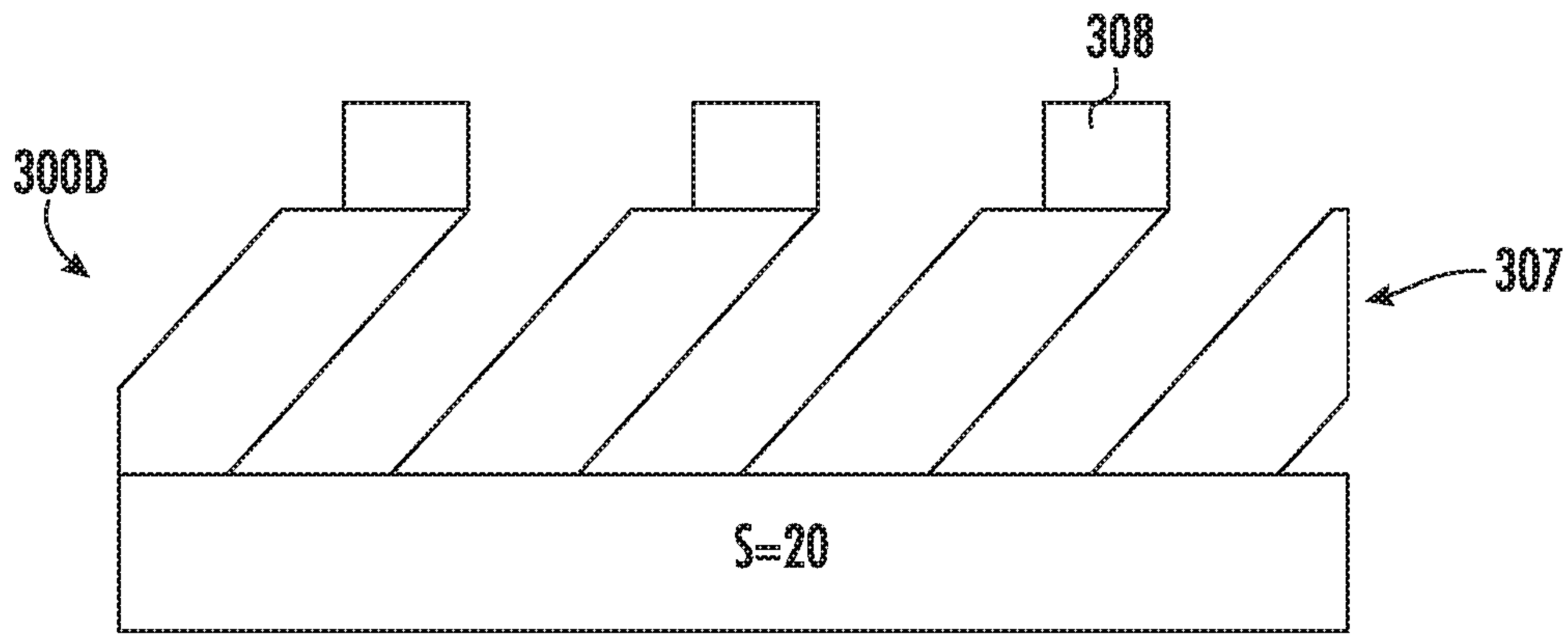


FIG. 6D

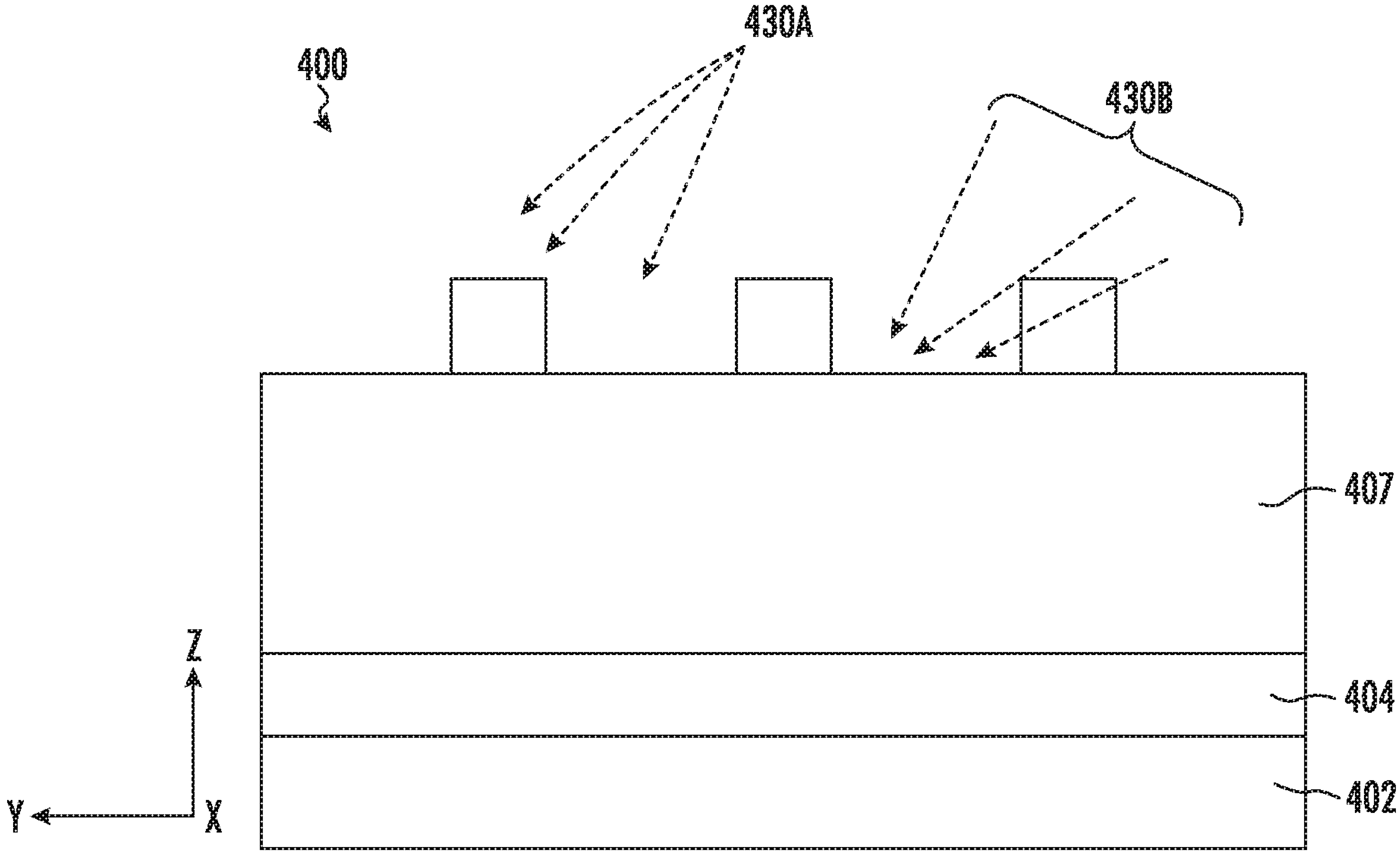

400
430A
430B
407
404
402
Z
Y
X

FIG. 7A

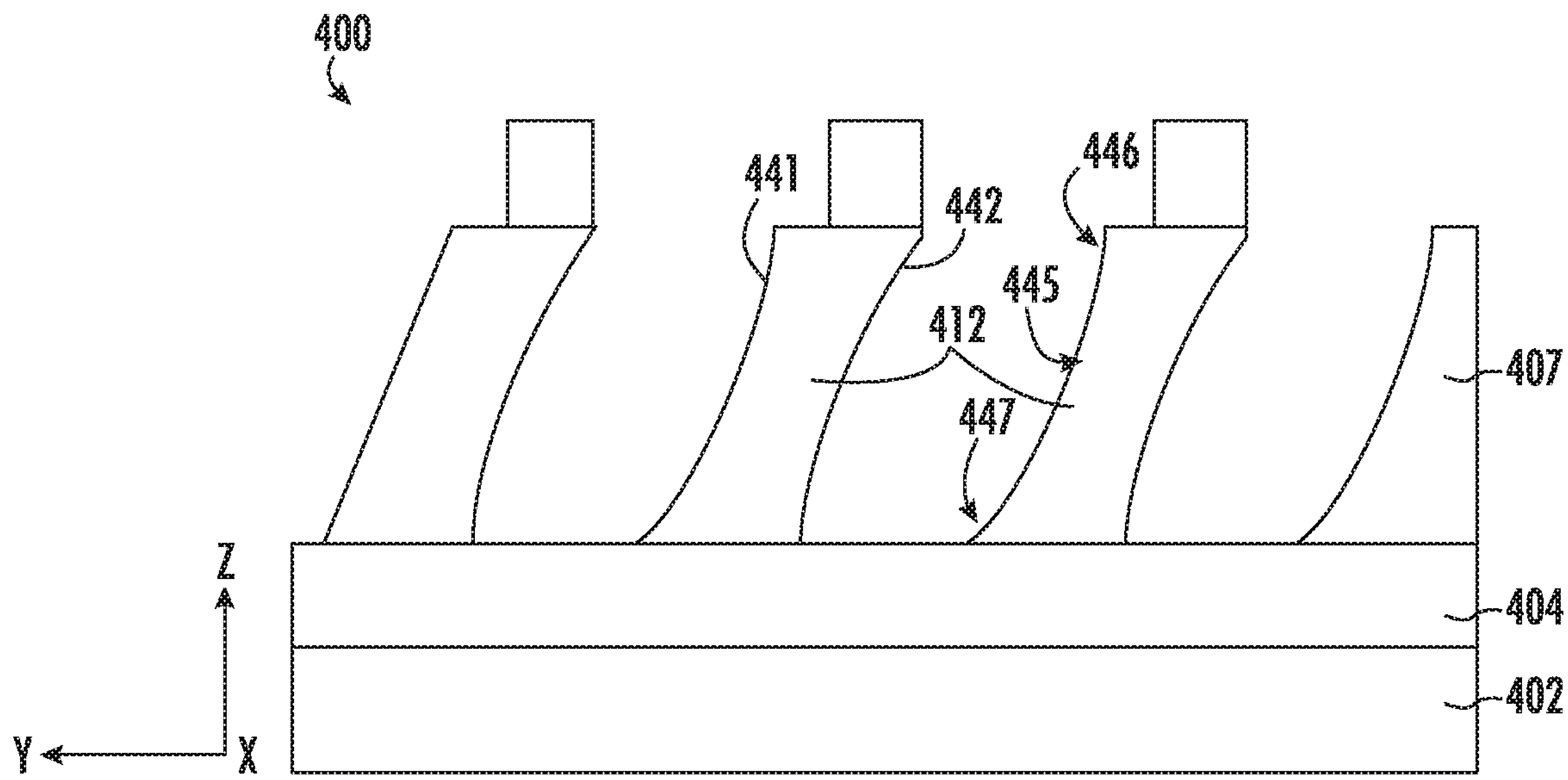

400
441
442
446
445
412
447
407
404
402
Z
Y
X

FIG. 7B

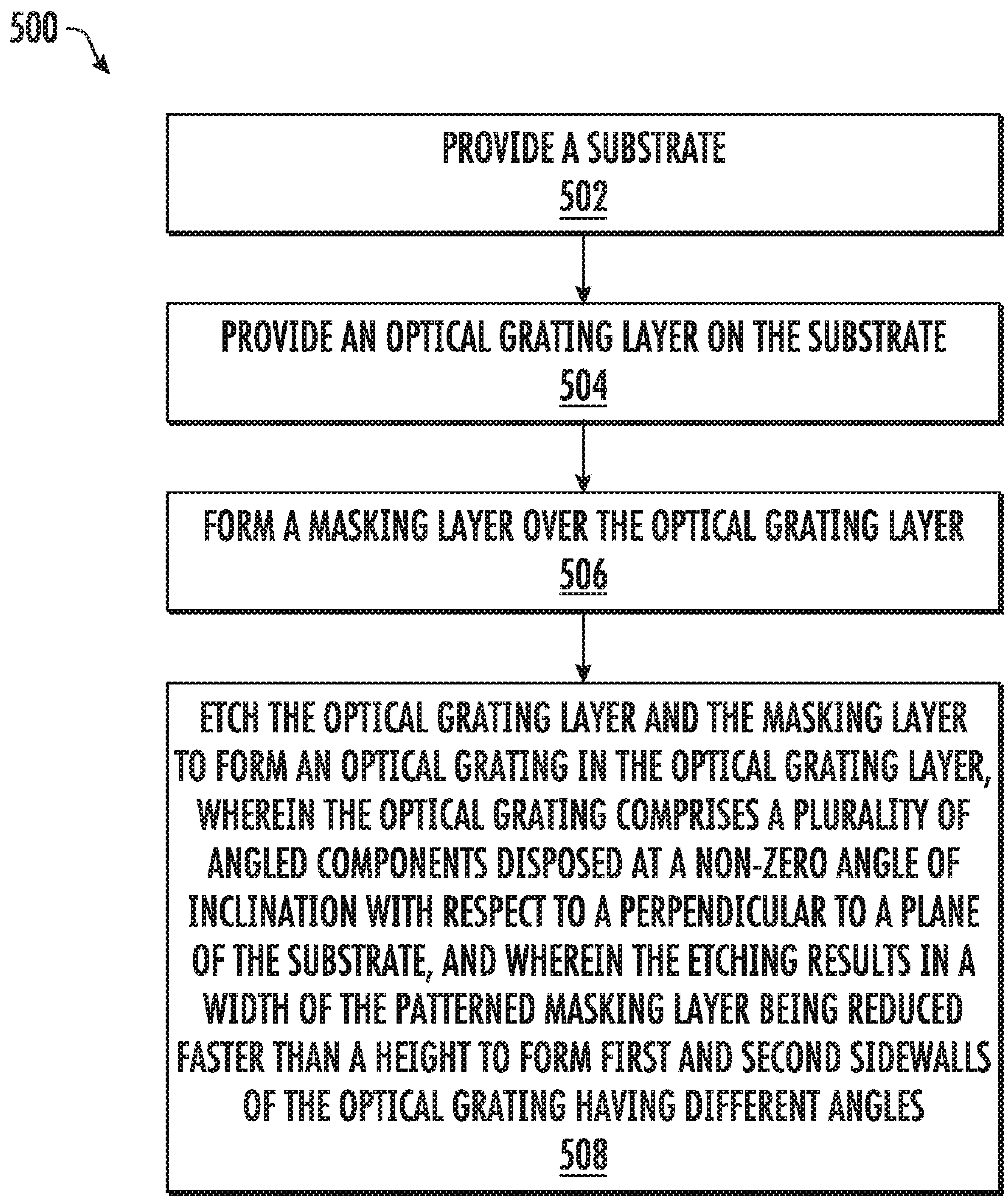

500
PROVIDE A SUBSTRATE
502
PROVIDE AN OPTICAL GRATING LAYER ON THE SUBSTRATE
504
FORM A MASKING LAYER OVER THE OPTICAL GRATING LAYER
506
ETCH THE OPTICAL GRATING LAYER AND THE MASKING LAYER TO FORM AN OPTICAL GRATING IN THE OPTICAL GRATING LAYER, WHEREIN THE OPTICAL GRATING COMPRISES A PLURALITY OF ANGLED COMPONENTS DISPOSED AT A NON-ZERO ANGLE OF INCLINATION WITH RESPECT TO A PERPENDICULAR TO A PLANE OF THE SUBSTRATE, AND WHEREIN THE ETCHING RESULTS IN A WIDTH OF THE PATTERNED MASKING LAYER BEING REDUCED FASTER THAN A HEIGHT TO FORM FIRST AND SECOND SIDEWALLS OF THE OPTICAL GRATING HAVING DIFFERENT ANGLES
508

FIG. 8

SYSTEM AND METHOD FOR OPTIMALLY FORMING GRATINGS OF DIFFRACTED OPTICAL ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application of U.S. Non-Provisional patent application Ser. No. 16/035,498 filed on Jul. 13, 2018, entitled "SYSTEM AND METHOD FOR OPTIMALLY FORMING GRATINGS OF DIFFRACTED OPTICAL ELEMENTS," and incorporated by reference herein in its entirety.

FIELD

This disclosure relates to optical elements, and more particularly to approaches for optimally forming gratings in diffracted optical elements.

BACKGROUND

Optical elements such as optical lenses have long been used to manipulate light for various advantages. Recently, micro-diffraction gratings have been utilized in holographic and augmented/virtual reality (AR and VR) devices.

One particular AR and VR device is a wearable display system, such as a headset, arranged to display an image within a short distance from a human eye. Such wearable headsets are sometimes referred to as head mounted displays, and are provided with a frame displaying an image within a few centimeters of the user's eyes. The image can be a computer generated image on a display, such as a micro display. The optical components are arranged to transport light of the desired image, where the light is generated on the display to the user's eye to make the image visible to the user. The display where the image is generated can form part of a light engine, so the image generates collimated light beams guided by the optical component to provide an image visible to the user.

Different kinds of optical components have been used to convey the image from the display to the human eye. To properly function in an augmented reality lens or combiner, the geometries of an optical grating may be designed to achieve various effects. In some devices, multiple different regions, such as two or more different regions, are formed on the surface of a lens, wherein the grating geometries in one region are different from the grating geometries in other regions. For example, many known devices include three elements: an incoupler, horizontal expander, and outcoupler. To provide these different regions, different etches are used to etch the gratings in different regions so the geometries of the gratings may differ among the different regions. Due to processing complexity, optimal parameters to achieve optical components with angled gratings are not known.

Therefore, with respect to at least the above drawbacks the present disclosure is provided.

BRIEF SUMMARY

In one embodiment, a method of forming an optical grating component is provided. The method may include providing an optical grating layer atop a substrate, and providing a hardmask atop the optical grating layer. The method may further include etching the optical grating layer and the hardmask to form an optical grating in the optical grating layer. The optical grating may include a plurality of

angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate. The etching results in a width of the patterned hardmask being reduced faster than a height to form first and second sidewalls of the optical grating having different angles.

In another embodiment, a method of forming an optical grating component may include providing an optical grating layer atop a substrate, and providing a patterned hardmask atop the optical grating layer. The method may further include etching the optical grating layer and the hardmask to form an optical grating in the optical grating layer, wherein the optical grating comprises a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate. The etching results in a width of the patterned hardmask being reduced faster than a height to form first and second sidewalls of the plurality of angled components having different angles.

In yet another embodiment, a method for forming an augmented reality/virtual reality device may include providing a patterned hardmask atop an optical grating layer, and etching the optical grating layer and the hardmask to form an optical grating in the optical grating layer. The optical grating may include a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate. The etching results in a width of the patterned hardmask being reduced faster than a height to form first and second sidewalls of the plurality of angled components having different angles.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate exemplary approaches of the disclosure, including the practical application of the principles thereof, as follows:

FIG. **1**A depicts a side cross sectional view of an optical grating component according to embodiments of the disclosure;

FIG. **1**B depicts a top plan view of the optical grating component of FIG. **1**A according to embodiments of the disclosure;

FIG. **2**A shows a processing apparatus, depicted in schematic form, in accordance with embodiments of the present disclosure;

FIG. **2**B shows an extraction plate component and substrate in top plan view in accordance with embodiments of the present disclosure;

FIG. **3** shows a side cross-sectional view of angled structures formed in an optical grating layer of optical grating component in accordance with embodiments of the present disclosure;

FIGS. **4**A-**4**D depict various stages in fabrication of an optical grating in accordance with embodiments of the present disclosure;

FIG. **5** is a graph demonstrating selectivity input versus output angles for sidewalls of the angled structure according to embodiments of the present disclosure;

FIGS. **6**A-**6**D depict various angled structures having different selectivity values in accordance with embodiments of the present disclosure;

FIG. **7**A is a side cross-sectional view depicting various ion beam angle spreads according to embodiments of the present disclosure;

FIG. 7B is a side cross-sectional view depicting a plurality of angled structures formed using the various ion beam angle spreads of FIG. 7A according to embodiments of the present disclosure;

FIG. 8 depicts a process flow in accordance with embodiments of the disclosure.

The drawings are not necessarily to scale. The drawings are merely representations, not intended to portray specific parameters of the disclosure. The drawings are intended to depict exemplary embodiments of the disclosure, and therefore are not be considered as limiting in scope. In the drawings, like numbering represents like elements.

DETAILED DESCRIPTION

The present embodiments will now be described more fully hereinafter with reference to the accompanying drawings, where some embodiments are shown. The subject matter of the present disclosure may be embodied in many different forms and are not to be construed as limited to the embodiments set forth herein. These embodiments are provided so this disclosure will be thorough and complete, and will fully convey the scope of the subject matter to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

As used herein, an element or operation recited in the singular and proceeded with the word "a" or "an" are understood as possibly including plural elements or operations, except as otherwise indicated. Furthermore, references to "one embodiment" or "some embodiments" of the present disclosure may be interpreted as including the existence of additional embodiments also incorporating the recited features.

Furthermore, the terms "approximate" or "approximately," can be used interchangeably in some embodiments, and can be described using any relative measures acceptable by one of skill. For example, these terms can serve as a comparison to a reference parameter, to indicate a deviation capable of providing the intended function. Although non-limiting, the deviation from the reference parameter can be, for example, in an amount of less than 1%, less than 3%, less than 5%, less than 10%, less than 15%, less than 20%, and so on.

Embodiments herein provide novel optical components and systems and methods for forming an optical component. Various embodiments are related to diffracted optical elements, where the term "optical grating component" refers to a device or part having an optical grating, including AR & VR headsets, eyepieces for AR & VR, or masters for forming optical gratings for eyepieces such as eyeglasses.

FIG. **1**A depicts a side cross sectional view of an optical grating component **100**, according to embodiments of the disclosure. FIG. **1**B depicts a top plan view of the optical grating component **100**. The optical grating component **100** may be used as an optical grating to be placed on an eyeglass or formed integrally in the eyeglass in accordance with various embodiments of the disclosure. The optical grating component **100** includes a substrate **102**, and optical grating **106**, disposed on the substrate **102**. In some embodiments, the substrate **102** is an optically transparent material, such as a known glass. In some embodiments, the substrate **102** is silicon. In the latter case, the substrate **102** is silicon, and another process is used to transfer grating patterns to a film on the surface of another optical substrate, such as glass or quartz. The embodiments are not limited in this context. The optical grating **106** may be disposed in an optical grating layer **107**, as described further below. In the embodiment of FIG. **1**A and FIG. **1**B, the optical grating component **100** further includes an etch stop layer **104**, disposed between the substrate **102** and optical grating layer **107**. According to some embodiments of the disclosure, the optical grating layer **107** may be an optically transparent material, such as silicon oxide, silicon nitride, glass, TiO_2, or other material.

According to some embodiments of the disclosure, the optical grating **106** may comprise a grating height H in the range of 100 nm to 1000 nm. As such, the optical grating **106** may be appropriate for use in an eyepiece of an AR & VR apparatus. Embodiments herein are not limited in this context. In accordance with some embodiments, the etch stop layer **104** may be an optically transparent material and may have a thickness of 10 nm to 100 nm. The embodiments are not limited in this context. Examples of a suitable material for the etch stop layer **104** include SiN, SiO_2, TiN, SiC, and other materials. In embodiments where the optical grating **106** is to be applied to or incorporated in an eyepiece of an eyeglass, an especially appropriate material is an optically transparent material. In embodiments where the optical grating component **100** forms a master for fabricating optical gratings for an eyepiece, the etch stop layer **104** need not be optically transparent. Moreover, the etch stop layer **104** may be omitted in some embodiments.

As further shown in FIG. **1**A, the optical grating **106** may comprise a plurality of angled structures, shown as angled structures **112**, disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate **102**. The angled structures **112** may be included within one or more fields of slanted gratings, the slanted grating together forming "micro-lenses." As will be described in greater detail below, the sidewalls **113** and **115** of each angled structure **112** may vary in angle (e.g., with respect to the perpendicular to the plane of the substrate **102**) and shape as beam selectivity, beam angle spread, beam angle mean, etc., are modified. As will be described in greater detail below, the sidewalls **113** and **115** of each angled structure **112** may further vary in angle based on the selectivity between the angled structures **112** and a hardmask formed over the angled structures **112**. As used herein, selectivity may be a product of the material(s) of the optical grating layer the angled structures **112** are formed, the chemistry of the etching ions, and tool parameters such as beam intensity, relative pressures of different gasses, and temperature.

Between the angled structures **112** is a plurality of trenches **114**. The angled structures **112** may be arranged to define a uniform or variable height along a first direction. In the example of FIG. **1**A, the angled structures **112** define a uniform height along the direction parallel to the Y-axis of the Cartesian coordinate system shown, where the first direction (Y-Axis) is parallel to the plane of the substrate **102**, in this case the X-Y plane. In other embodiments, the angled structures **112** may define a variable height along the direction parallel to the Y-axis.

The width of the optical grating **106** along the Y-direction may be on the order of several millimeters to several centimeters, while the grating height H may be on the order of 1 micrometer or less. Accordingly, the variation in grating height H may range on the order of several hundred nanometers or less. An example of a smooth variation in grating height H or depth d is where a change in grating height H or depth d between adjacent lines of a grating is less than 10%, less than 5%, or less than 1%. The embodiments are not limited in this context. Thus, in an eyepiece, the grating height H may vary continuously and in a non-abrupt fashion in a given direction along the surface of the eyepiece over a distance of, for example, millimeters to centimeters. More particularly, a change in grating height H of 50% over a 5 mm distance may entail changing the grating height H continuously over approximately 5×10^3 lines having a pitch of one micrometer. This change entails an average change in relative height of adjacent lines of $0.5/5\times10^4$ or approximately 0.01%.

Turning now to FIG. **2**A, there is shown a processing apparatus **200**, depicted in schematic form. The processing apparatus **200** represents a processing apparatus for etching portions of a substrate, or depositing on a substrate, to generate, for example, the optical gratings of the present embodiments. The processing apparatus **200** may be a plasma based processing system having a plasma chamber **202** for generating a plasma **204** therein by any convenient method as known in the art. An extraction plate **206** may be provided as shown, having an extraction aperture **208**, where a non-uniform etching or non-uniform deposition may be performed to reactively etch or deposit an optical grating layer **107** (FIGS. **1**A-B). A substrate **102**, including, for example, the aforementioned optical grating structure, is disposed in the process chamber **224**. A substrate plane of the substrate **102** is represented by the X-Y plane of the Cartesian coordinate system shown, while a perpendicular to the plane of the substrate **102** lies along the Z-axis (Z-direction).

As further shown in FIG. **2**A, an ion beam **210** may be extracted when a voltage difference is applied using bias supply **220** between the plasma chamber **202** and substrate **102**, or substrate platen **214**, as in known systems. The bias supply **220** may be coupled to the process chamber **224**, for example, where the process chamber **224** and substrate **102** are held at the same potential.

According to various embodiments, the ion beam **210** may be extracted along the perpendicular **226** or may be extracted at a non-zero angle of incidence, shown as ϕ, with respect to the perpendicular **226**.

The trajectories of ions within the ion beam **210** may be mutually parallel to one another or may lie within a narrow angular spread range, such as within 10 degrees of one another or less. In other embodiments, as will be discussed below, the trajectory of ions within the ion beam **210** may converge or diverge from one another, for example, in a fan shape. Thus, the value of ϕ may represent an average value of incidence angle where the individually trajectories vary up to several degrees from the average value. In various embodiments, the ion beam **210** may be extracted as a continuous beam or as a pulsed ion beam as in known systems. For example, the bias supply **220** may be configured to supply a voltage difference between the plasma chamber **202** and the process chamber **224**, as a pulsed DC voltage, where the voltage, pulse frequency, and duty cycle of the pulsed voltage may be independently adjusted from one another.

In various embodiments, gas, such as reactive gas, may be supplied by the source **222** to plasma chamber **202**. The plasma **204** may generate various etching species or depositing species, depending upon the exact composition of species provided to the plasma chamber **202**.

In various embodiments, the ion beam **210** may be provided as a ribbon reactive ion beam having a long axis extending along the X-direction of the Cartesian coordinate system shown in FIG. **2**B. By scanning a substrate platen **214** including substrate **102** with respect to the extraction aperture **208**, and thus with respect to the ion beam **210** along the scan direction **230**, the ion beam **210** may etch the substrate **102** or deposit upon the substrate **102**. The ion beam **210** may be composed of any convenient gas mixture, including inert gas, reactive gas, and may be provided in conjunction with other gaseous species in some embodiments. In particular embodiments, the ion beam **210** and other reactive species may be provided as an etch recipe to the substrate **102** so as to perform a directed reactive ion etching of a layer, such as the optical grating layer **107**. Such an etch recipe may use known reactive ion etch chemistries for etching materials such as oxide or other material, as known in the art. In other embodiments, the ion beam **210** may be formed of inert species where the ion beam **210** is provided to etch the substrate **102** or more particularly, the optical grating layer **107**, by physical sputtering, as the substrate **102** is scanned with respect to ion beam **210**.

In the example of FIG. **2**B, the ion beam **210** is provided as a ribbon reactive ion beam extending to a beam width along the X-direction, where the beam width is adequate to expose an entire width of the substrate **102**, even at the widest part along the X-direction. Exemplary beam widths may be in the range of 10 cm, 20 cm, 30 cm, or more while exemplary beam lengths along the Y-direction may be in the range of 2 mm, 3 mm, 5 mm, 10 mm, or 20 mm. The embodiments are not limited in this context.

Notably, the scan direction **230** may represent the scanning of substrate **102** in two opposing (180 degrees) directions along the Y-direction, or just a scan toward the left or a scan toward the right. As shown in FIG. **2**B, the long axis of ion beam **210** extends along the X-direction, perpendicularly to the scan direction **230**. Accordingly, an entirety of the substrate **102** may be exposed to the ion beam **210** when scanning of the substrate **102** takes place along a scan direction **230** to an adequate length from a left side to right side of substrate **102**.

In various embodiments, as will be detailed below, the processing apparatus **200** may be used to form an optical grating layer, having varied features such as angles, thicknesses, and depths. The grating features may be accomplished by scanning the substrate **102** with respect to the ion beam **210** using a processing recipe. In brief, the processing recipe may entail varying at least one process parameter of a set of process parameters, having the effect of changing, e.g., the etch rate or deposition rate caused by the ion beam **210** during scanning of the substrate **102**. Such process parameters may include the scan rate of the substrate **102**, the ion energy of the ion beam **210**, duty cycle of the ion beam **210** when provided as a pulsed ion beam, the spread angle of the ion beam **210**, and rotational position of the substrate **102**. In at least some embodiments herein, the processing recipe may further include the material(s) of the optical grating layer **107**, and the chemistry of the etching ions **130**. In yet other embodiments, the processing recipe may include starting geometry of the optical grating layer **107**, including dimensions and aspect ratios, as well as the presence of the etch stop layer **104**, including whether under or over etching into the etch stop layer **104** is intended. The embodiments are not limited in this context. Because the deposition rate or etch rate caused by the ion beam **210** may vary during scanning of the substrate **102**, the thickness or height of the optical grating layer **107** may vary along the scan direction (Y-axis), generating (after further process operations, detailed below) the resultant structure as shown in FIG. **1**A.

Turning now to FIG. **3**, an example set of fins or angled structures **112** formed in the optical grating layer **107** by the etch processes of the embodiments herein will be described in greater detail. The angled structures **112** may be formed by any of the above described etch processes to manufacture the angled structures **112** with unique locations, shapes, three dimensional orientations, etc. In some examples, the etch processes are capable of controlling or modifying any of the following grating parameters of the set of angled structures **112**: pitch, hardmask **108** thickness, and fin height. The etch processes are also capable of controlling or modifying any of the following grating parameters of the set of angled structures **112**: fin thickness (CD), corner radius β and α, over-etch into the etch stop layer **104**, heeling, first sidewall angle ρ, second sidewall angle θ, and footing. In one non-limiting embodiment, based on the selectivity and geometry (e.g., height and width) of the hardmask **108**, as well as the geometry of the optical grating layer **107**, the hardmask **108** over each of the angled structures **112** may be etched away horizontally faster than vertically to form a pointed tip along each of the angled structures **112**.

Turning now to FIG. **4**A there is shown a side cross-sectional view of the optical grating component **100** at one instance of fabrication. In the instance shown, an optical grating layer **107** having uniform height is disposed on the etch stop layer **104**. A hardmask **108**, such as a hard mask, has been formed/patterned on the optical grating layer **107**. The hardmask **108** may be formed of material such as carbon, SiO_2, SiC, AlO_x, ZrO_x, and so forth. In accordance with various embodiments, a directional reactive ion etching process is performed to etch the optical grating layer **107**. The directional reactive ion etch is represented by etching ions **130**. The etch chemistry may include the etching ions **130** as well as other non-ionic species, and may be chosen according to known reactive ion etch compositions for selectively etching the optical grating layer **107** and not the hardmask **108**. For example, the etch chemistry may be chosen to selectively etch SiO_2 with respect to carbon in one example. In other embodiments, the etch chemistry and etch angle may be chosen according to known reactive ion etch compositions for selectively etching both the optical grating layer and the hardmask **108**.

The etching ions **130** may be provided as a ribbon reactive ion beam, with the ion trajectories of the ribbon reactive ion beam defining a non-zero angle of inclination μ with respect to the perpendicular **132**, as shown. The non-zero angle of incidence may be generated according to known techniques, such as using a beam blocker adjacent the extraction aperture **208**, adjusting the extraction aperture width along the Y-axis, as well adjusting plasma conditions within the plasma **204**, including gas pressure, to change the curvature of the plasma sheath boundary **228**, proximate the extraction aperture **208**.

According to some embodiments of the disclosure, designed or theoretical input values for a given optical grating may be calculated to optimize performance of the optical grating. This grating profile may then be used to program the processing recipe for the processing apparatus **200** to generate the grating profile in the optical grating layer **107** using etching ions **130**.

In FIG. **4**B, a further instance of processing the optical grating component **100** is shown. In non-limiting embodiments, the optical grating layer **107** has been partially etched by the etching ions **130** to begin forming the angled structures **112**, separated by a plurality of trenches **114**. Based on the selectivity and geometry of the hardmask **108**, as well as the height "H" or thickness of the optical grating layer **107** and the width "W" of the optical grating layer **107**, the hardmask **108** over each of the angled structures **112** etches away horizontally (shown by arrow **155**) faster than vertically (shown by **157**). By doing so, the angled structures **112** are formed with non-parallel sidewalls. The etching ions **130** may further deepen the plurality of trenches **114**, as shown in FIG. **4**C. In non-limiting embodiments, the angled structures **112** define the first sidewall angle ρ and the second sidewall angle θ, wherein p≠θ. As shown, θ becomes increasing larger relative to ρ over a series of etch cycles.

Although not shown, according to various embodiments, the etch chemistry for the etching ions **130** is arranged so the optical grating layer **107** is also selectively etched with respect to the etch stop layer **104** and to the hardmask **108**. For example, once the etch stop layer **104** is encountered, etching slows and the process of etching ions **130** may be conveniently terminated. Once formed, the angled structures **112** define the first sidewall angle ρ and the second sidewall angle θ. As the optical grating layer **107** is etched, so too is the hardmask **108**, e.g., at a rate <<20:1 until the hardmask **108** is gone, as shown in FIG. **4**D. As shown, the angles ρ and θ are not the same, and thus the sides of the angled structures **112** of the optical grating layer **107** are not parallel. Instead, the first sidewall angle ρ and the second sidewall angle θ diverge as the optical grating layer **107** is etched to a top surface **144** of the etch stop layer **104**.

As further shown in FIG. **4**D, over-etch into the etch stop layer **104** is minimal, and the trenches **114** adjacent the top surface **144** of the etch stop layer **104** are relatively flat/planar. In the instance shown, the selectivity (S) value is lower (e.g., S=2), thus causing the angle θ of the first sidewall(s) **141** and the angle ρ of the second sidewall(s) **142** to have a larger difference.

The relationship between selectivity input and output angles ρ and **0**, is shown in the graph **250** of FIG. **5**. In exemplary embodiments, increasing the selectivity causes the angle ρ of the first sidewall and the angle θ of the second sidewall to become more parallel. In a theoretical example, the selectivity is selected to be 50, thus leading to parallel, or nearly parallel sidewalls for each angled component. As shown, the angle ρ of the first sidewall and the angle θ of the second sidewall become generally parallel when S>10.

The embodiments of FIGS. **6**A-**6**D demonstrate various optical grating components having different selectivity values (S). For example, S=2 for the optical grating component **300**A in FIG. **6**A, S=5 for the optical grating component **300**B in FIG. **6**B, S=10 for the optical grating component **300**C in FIG. **6**C, and S=20 for the optical grating component **300**D in FIG. **6**D. As the selectivity increases, the sidewalls of the angled components become more parallel. As further shown, higher selectivity values results in the hardmask **308** remaining atop each angled structure of the optical grating layer **307**.

In another embodiment, as shown in FIG. **7**A, ion beam angle spread (BAS) and/or beam angle mean impacting an optical grating layer **407** of an optical grating component **400** provided on a substrate **402** can be varied. For example, the directional reactive ion etch represented by etching ions **430**A may be a diverging beam spread, while the directional reactive ion etch represented by etching ions **430**B may be a converging beam spread. As shown in FIG. **7**B, by varying the BAS, either converging or diverging, the first sidewall **441** and the second sidewall **442** of each of the fins **412** may be curved or concave. In some embodiments, a central part **445** of each fin **412** is more narrow (e.g., in the +–y-direction) than upper and lower portions **446** and **447**, respectively. Increasing the BAS may cause a greater curve of each fin **412**. In other embodiments, increasing the BAS by too much, while also selecting an over-etch of the etch stop layer **404**, may cause overly bowed fins, and/or fins with thinning along the lower portions. Accordingly, BAS and over-etch are to be optimized when selected together as part of the processing recipe.

In accordance with additional embodiments of the disclosure, fabrication of a plurality of optical gratings may be readily accomplished by performing variants of the processing of an optical grating layer discussed above. In some embodiments, a plurality of optical grating regions may be prepatterned on one substrate or multiple substrates, where the substrate or substrates are placed on the substrate platen **214** (FIGS. **2**A-**2**B). In particular embodiments, a substrate having a plurality of different optical grating fields may be fabricated where the direction of the angled features in one optical grating field differs from another optical grating field. By way of background, known AR eyepieces may be formed when multiple different optical gratings are arranged on a transparent eyepiece to form "micro-lenses." A first optical grating may have angled structures oriented from top to bottom of the eyepiece, while a second optical grating may have angled structures oriented from left to right on the eyepiece.

While the above embodiments are mostly detailed within the context of forming optical gratings directly in an eyepiece, in other embodiments, the same grating structure as shown in FIGS. **1**A, **1**B, **5**A and/or **5**B, for example, may be used to form a master. Said differently, the optical grating components, or similar grating components such as a Si wafer, with or absent the etch stop layer and the hardmask, may serve as a master to imprint a grating pattern into an optical grating layer on an eyepiece, or to be applied to an eyepiece. Notably, in embodiments where the optical grating component is to serve as a master, the substrate, the etch stop layer, if included, as well as the optical grating layer, need not be optically transparent.

Moreover, while the aforementioned embodiments focus on ribbon reactive ion beams to perform processing, as well as angled etching, in various embodiments a beam, such as a radical beam may be used to perform etching.

Furthermore, embodiments herein may be computer implemented. For example, the processing apparatus **200** may include a computer processor to perform logic operations, computational tasks, control functions, etc. In some embodiments, the computer processor may be a component of a processor. The computer processor may include one or more subsystems, components, modules, and/or other processors, and may include various logic components operable using a clock signal to latch data, advance logic states, synchronize computations and logic operations, and/or provide other timing functions. During operation, the computer processor may receive signals transmitted over a LAN and/or a WAN (e.g., T1, T3, 56 kb, X.25), broadband connections (ISDN, Frame Relay, ATM), wireless links (802.11, Bluetooth, etc.), and so on. In some embodiments, the signals may be encrypted using, for example, trusted key-pair encryption. Different systems may transmit information using different communication pathways, such as Ethernet or wireless networks, direct serial or parallel connections, USB, Firewire®, Bluetooth®, or other proprietary interfaces. (Firewire is a registered trademark of Apple Computer, Inc. Bluetooth is a registered trademark of Bluetooth Special Interest Group (SIG)).

In general, the computer processor executes computer program instructions or code stored in a memory unit and/or storage system. For example, when executing computer program instructions, the computer processor causes the processing apparatus **200** to receive inputs, such as any of the processing parameters discussed herein, and provide, from the computer processor, the outputs. In some embodiments, the computer processor executes and carries out the processing recipe to form optical grating components **100**, **300**A-D, and **400**.

While executing computer program code, the computer processor can read and/or write data to/from the memory unit and/or the storage system. The storage system may comprise VCRs, DVRs, RAID arrays, USB hard drives, optical disk recorders, flash storage devices, and/or any other data processing and storage elements for storing and/or processing data. Although not shown, the processing apparatus **200** could also include I/O interfaces communicating with one or more hardware components of computer infrastructure to enable a user to interact with the processing apparatus **200** (e.g., a keyboard, a display, camera, etc.).

Turning now to FIG. **8**, a method **500** according to embodiments of the present disclosure will be described in greater detail. Specifically, at block **502**, a substrate is provided. In some embodiments, the substrate is silicon. In other embodiments, the substrate may be a transparent material, such as glass.

At block **504**, an optical grating layer is formed over the substrate. In some embodiments, the optical grating layer may comprise an optically transparent material, including, yet not limited to, silicon oxide, silicon nitride, glass, or other material. In some embodiments, the optical grating layer is formed atop an etch stop layer. The etch stop layer may be an optically transparent material and may have a thickness of 10 nm to 100 nm.

At block **506**, a hardmask is formed on the optical grating layer. In some embodiments, the mask includes a linear pattern. The linear pattern may have linear mask elements extending along a second direction, perpendicular to the first direction, or scan direction. In other embodiments, the mask includes a non-linear pattern. For example, the masking pattern may include one or more curved elements.

At block **508**, an optical grating may be formed in the optical grating layer. In some embodiments, the optical grating includes a plurality of angled components, disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate, etching the optical grating layer and the hardmask to form an optical grating in the optical grating layer. The optical grating may include a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate. The etching results in a width of the patterned hardmask being reduced faster than a height to form first and second sidewalls of the optical grating having different angles.

In some embodiments, block **508** includes forming the optical grating by performing an angled reactive ion etch into the optical grating layer. The angled reactive ion etch is formed by a ribbon reactive ion beam, and wherein the substrate is scanned along a scan direction with respect to the ribbon reactive ion beam using a processing recipe. In some embodiments, the ribbon reactive ion beam has a converging or diverging beam spread.

In some embodiments, the processing recipe may be modified. For example a higher selectivity value may result in a first differential between the first angle of the first sidewall and the second angle of the second sidewall. A lower selectivity value may result in a second differential between the first angle of the first sidewall and the second angle of the second sidewall, and wherein the first differential is less than the second differential.

The processing recipe may include a plurality of process parameters having an effect of changing a shape or dimension of the plurality of angled components. The plurality of processing parameters may include one or more of the following: a material of the optical grating layer, a chemistry of the ribbon reactive ion beam relative to a chemistry of the optical grating layer and of the making layer, and a ribbon reactive ion beam intensity. The plurality of processing parameters may further include a relative pressure of different gasses used to form the ribbon reactive ion beam, a temperature to form the ribbon reactive ion beam, a ribbon reactive ion beam angle, a ribbon reactive ion beam spread, and presence of the etch stop layer.

In other embodiments, block **508** includes forming a master optical grating on a wafer (e.g., Si wafer), and then transferring the pattern to an optically transparent substrate for use. For example, the pattern is transferred from the Si wafer to the optical grating layer using a nano imprint lithography (NIL) process.

In sum, various embodiments described herein provide approaches for forming optical grating components including eyepieces for AR & VR, or masters for forming optical gratings for AR&VR eyepieces. Manufacturing may be accomplished by direct application of the angled ions on the substrate, and/or on a mask used to transfer the pattern to the substrate of interest. A first technical advantage of the present embodiments includes optimization of post processing, as some shapes are less desirable for subsequent processing, such as Nano Imprint Lithography (NIL). A second technical advantage is optimization of the shape and size of the optical grating, thus translating to optical "bending" power. 2-D projection systems according to the embodiments herein entail a more sophisticated, numerous, and distributed optical.

The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are intended to fall within the scope of the present disclosure. Furthermore, the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose. Those of ordinary skill in the art will recognize the usefulness is not limited thereto and the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Thus, the claims set forth below are to be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. A method of forming an optical grating component, comprising:

providing a patterned hardmask atop an optical grating layer, wherein the optical grating layer is formed atop an etch stop layer; and

etching the optical grating layer and the patterned hardmask to form an optical grating in the optical grating layer, wherein first and second sidewalls of the optical grating have different angles, and wherein the optical grating layer is etched selective to a top surface of the etch stop layer.

2. The method of claim **1**, wherein the optical grating comprises a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of a substrate.

3. The method of claim **2**, further comprising forming first and second sidewalls of one or more of the plurality of angled components of the optical grating at different angles.

4. The method of claim **2**, wherein the etching comprises etching the optical grating layer using an angled reactive ion etch.

5. The method of claim **4**, wherein the angled reactive ion etch is performed by a ribbon reactive ion beam, wherein the substrate is scanned along a scan direction with respect to the ribbon reactive ion beam using a processing recipe, and wherein the ribbon reactive ion beam has a beam angle mean and a beam spread, the beam spread being one of: converging or diverging.

6. The method of claim **1**, further comprising etching the patterned hardmask to remove the patterned hardmask before the optical grating layer is removed to the top surface of the etch stop layer.

7. The method of claim **1**, further comprising etching the first sidewall and the second sidewall to have a curved geometry.

8. The method of claim **1**, further comprising forming the optical grating by:

forming a pattern into a wafer; and

transferring the pattern to the optical grating layer using a nano imprint lithography process.

9. A method of forming an optical grating component, comprising:

providing a patterned hardmask atop an optical grating layer, wherein the optical grating layer is formed atop a substrate; and

etching the optical grating layer and the patterned hardmask to form an optical grating in the optical grating layer, wherein the optical grating layer is etched through a series of openings defined by the patterned hardmask using an angled reactive ion etch, wherein the optical grating comprises a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate, wherein a first sidewall and a second sidewall of at least one angled component of the plurality of angled components are oriented at different angles with respect to the perpendicular to the plane.

10. The method of claim **9**, wherein the angled reactive ion etch is performed by a ribbon reactive ion beam, wherein the substrate is scanned along a scan direction with respect to the ribbon reactive ion beam.

11. The method of claim **9**, wherein the etching causes the patterned hardmask to be removed before the optical grating layer is removed to a top surface of an etch stop layer.

12. The method of claim **9**, further comprising forming the first sidewall and the second sidewall with a curved geometry.

13. A method for forming an augmented reality/virtual reality device, the method comprising:

providing a patterned hardmask atop an optical grating layer; and

etching the optical grating layer and the patterned hardmask to form an optical grating in the optical grating layer, wherein the etching results in a width of the patterned hardmask being reduced faster than a height to form first and second sidewalls of a plurality of angled components of the optical grating having different angles.

14. The method of claim **13**, further comprising forming the plurality of angled components of the optical grating using an angled reactive ion etch.

15. The method of claim **14**, wherein the angled reactive ion etch is performed by a ribbon reactive ion beam, wherein the optical grating layer is scanned along a scan direction with respect to the ribbon reactive ion beam using a processing recipe, and wherein the ribbon reactive ion beam has a beam angle mean and a beam spread, the beam spread being one of: converging or diverging.

16. The method of claim **13**, wherein the etching results in the first sidewall and the second sidewall having a curved geometry.

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